PROPER MOTIONS OF THE NEBULÆ.

By H. D. Curtis.

Particularly in connection with the radial velocities which have recently been found for a limited number of the nebulæ, a knowledge of nebular proper motions would be of great value in investigations as to the size and the distance of these bodies. It is most unfortunate that we have no old observations of nebulæ which can compare in accuracy with the positions of the stars determined a century or more ago, and which to-day form so valuable an asset in determining stellar proper motions. We have the element of time given us in the nebular observations made by the elder Herschel, but the probable error of his positions is a matter of minutes of arc, rather than seconds. Even when we come to the much more carefully made observations in the middle of the last century, any comparison of these positions with modern positions proves entirely illusory. Except for a very small number of sharply defined objects the older observations of the nebulæ are as valueless for the determinations of the motions of these bodies as are the old sketches in giving an adequate idea of their form and structure; photographic methods, plus the all-important factor of a sufficient time interval, will give us the only trustworthy data for the determination of nebular proper motions, as it has given the only trustworthy delineation of nebular forms.

It is now about sixteen years since Director Keeler inaugurated his program of nebular photography with the Crossley Reflector. It was early realized that this collection of photographs of 104 nebulæ and clusters was in many respects a unique one in its epoch and extent, and that it would some day serve as a valuable basis for determination of nebular motions or changes. One of the programs of work at the Lick Observatory has been to repeat the early photographs in the search for such changes, and also to collect as many additional photographs of nebulæ as possible to form the basis of more extended motion determinations in the future.

This program of repetition is now practically completed. The average time interval between the early and the late plates

is 13.85 years; the total number of objects measured is 140, divided as follows:—

Large, diffuse nebulosities, *Orion, Network,* etc.	10
Planetary, annular and others showing gaseous spectrum (excluding diffuse nebulosities of the *Orion* type)	17
Very small nebulæ, most of which are probably spirals	47
Large spiral nebulæ	66

Inasmuch as both series of plates were taken with the same instrument, the methods of measurement have been made entirely differential, and, with the exception of one bright planetary for which no old plate existed, no attempt has been made to determine right ascensions and declinations and to compare thus with older visual observations. To some it may seem that thereby an opportunity has been lost, but such a procedure would have resulted in a considerable loss of accuracy. This loss in accuracy would come not only from the inaccuracy of the old visual observations, the probable errors of which are generally larger than the small motions to be determined, but also from the fact that even when sufficient comparison stars are found on the negatives, these stars, of the eighth or ninth magnitude, show such large images in exposures of two to four hours, that no very accurate settings can be made. Five or six symmetrically placed small stars of from the twelfth to the fifteenth magnitude were selected as a common reference system for all the plates of a given nebula, and the nucleus and numerous knots and condensations were measured as available in each nebula.

The accuracy of the measures varies considerably, from the nature of the case, in the different classes of nebulæ measured, and would be much higher were the old plates as uniformly sharp and good as the late plates. Owing to the deficiencies of the old mounting of the Crossley really excellent plates are the exception in the early series.

Quite a large proportion of the old plates, while adequate in giving the essential appearance of the nebulæ, would be rejected to-day. In making this statement I have no intention of belittling the work done by the early observers with the Crossley; a survey of all the older Crossley plates, with its large percentage of poor plates or absolute failures, tends

rather to give one a feeling of admiration at the pluck and determination of these observers in persevering and securing as good results as they did with a deficient and inadequate mounting. The problem resolves itself into making the best of the old series as it stands, inasmuch as for many of the nebulæ of this program a single plate taken by KEELER, PALMER or PERRINE forms the only existing photographic record prior to 1902.

The general results, by classes, are as follows:—

1. *Large, Diffuse Nebulosities.* This class includes such nebulæ as the *Orion,* the *Network* Nebula, the *Trifid,* M. 8 *Sagittarii,* etc. From the nature of the case the measurements on the delicate wisps, lanes, and holes in these complex and remarkable objects are very difficult, and the errors of measurement relatively large. For all ten objects the average relative yearly proper motion is 0."036. This, of course, means very little; the most that can be said, both from the measures and from careful examination, is that there has pretty certainly been no change in any of the intricate formations of these enormous objects as large as one second of arc during the past fifteen years.

2. *Planetary and Annular Nebulæ.* Nearly all these have a very sharp stellar nucleus. The exposures necessary are only two or three minutes, and in many cases several images are available for measurement, so that the resulting proper motions seem entitled to greater weight than those of any of the other types of nebulæ measured. The average relative yearly proper motion for the seventeen objects in this class is 0."028; the largest motions found are those for N. G. C. 6905 and 7009, 0."056 and 0."054 respectively.

3. *Very Small Nebulæ.* Only those were selected which showed a well marked central condensation or nucleus, and no attempt was made to get the faintest objects of this class. Many of them show faint evidences of spiral character, and probably the majority of them are in reality of this type. The average proper motion per year is 0."040. It seems certain that none of these objects has moved as much as one second of arc during the past fifteen years.

4. *Large Spiral Nebulæ.* The 66 objects in this class in-

clude not only the larger spirals, but also a number of lens-shaped objects which are doubtless spirals seen edge on. For ten objects it was found possible to make measures on the nucleus alone; for the others settings were made on from two to fourteen stellar condensations, which, tho generally hazy and indistinct, are beautifully sharp in a few cases. For some of the better spirals the agreement of the measures on the different condensations is quite good, and the motion seems well determined. Several spirals show a proper motion of six to nine hundredths of a second of arc per year, but these cases all occur where only a diffuse nucleus was measurable or where the old plate is distinctly poor; I have not, however, thot it best to reject these values. The nebula N. G. C. 253, in which nine condensations were measured on plates taken in 1902, 1907 and 1915, shows the largest proper motion in this class, which seems worthy of confidence, viz., $-0.''072$ in $\alpha \cos\delta$ and $+0.''028$ in δ. The average yearly relative motion for the 66 large spirals is $0.''033$. A number of the better determined nebulæ showing numerous condensations were examined graphically for possible evidences of rotation, but none were found. A much greater time interval will be necessary before nebular rotations can be definitely established by measures of position, unless a nebula abnormally close to us be found, and reliance must be had on spectroscopic methods, whose results are independent of the distance of the object.

Altho astronomical literature is already all too full of deductions made from an insufficient number of objects, it may be of interest to use the confessedly meager body of data at present available to obtain an estimate of the distances of the planetary nebulæ and the large spirals.

The average radial velocity of 73 planetary type nebulæ from recent Lick observations is thirty-nine kilometers per second. This value, combined with the average proper motion found, would make the average distance of this class of nebulæ about one thousand light-years, a value which is not improbable, as all these objects are Milky Way phenomena.

The radial velocities of very few spirals have been determined as yet; the mean of SLIPHER'S results is 400 kilometers per

second, a truly enormous value, which may be considerably changed when a larger number have been determined. On this basis and on the assumption that these objects are moving truly at random in space, the average distance of the spirals is of the order of ten thousand light-years, a distance which many will regard as too small.